Gas metallicities and early evolution of distant radio galaxies.

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Abstract.

By modeling the rich emission line spectra of a sample of high redshift (HzRG, $z \sim$2.5) radio galaxies we find that solar and supersolar metallicities are common in the extended gas of these objects. Our models and the comparison with high redshift quasars suggest that HzRG at $z \sim$2.5 are associated with intense star formation activity. This is consistent with chemical evolution models for giant ellipticals and it supports the idea that distant powerful radio galaxies are progenitors of giant ellipticals. We might be witnessing different evolutive status in different objects.

Keywords: elliptical galaxies, abundances, galaxy evolution

1. Introduction

High redshift radio galaxies ($z >$2, HzRG) are believed to be progenitors of giant ellipticals (CDs) (Best et al. 1998, McLure & Dunlop 2000). The study of the early stages of the formation and evolution of these massive (proto-)galaxies is of primary importance to understand galaxy formation scenarios.

Some of the important questions about HzRG concern the evolutionary status of the underlying galaxy and the connection between the formation of the galaxy and the central black hole. Is the host galaxy fully formed yet? Is there an underlying old stellar population or maybe the galaxy has not even formed the bulk of its stars yet?

It has been discussed in this meeting how metal abundances (constrained from the SED, absorption and/or emission lines) can be used as probes of star formation and galaxy evolution. We show in this paper how we have used the emission line spectra (in particular, the NVλ1240 line) of a sample of HzRG to constrain the gas metal abundances and the conclusions we draw about the evolutionary status of these galaxies.

2. The data and the modeling code

The spectra of 9 HzRG ($2.3 \leq z \leq 3.6$) were obtained with the Low Resolution Imaging Spectrometer at the Keck II telescope. Detailed description of the sample, observing runs and data reduction will be presented in Vernet et al. (2001, in prep.). See also Fosbury et al. (1999).

We used the multipurpose code Mappings Ic developed by Luc Binette. See (Villar-Martín et al., 1999) for the modeling method.

3. The "NV diagram"

Hamann and Ferland (1993, 1999) (HF93, HF99) showed that high redshift quasars ($z > 2$) define a tight correlation on the diagnostic diagram NVλ1240/HeIIλ1640 vs. NV/CIVλ1550. The modeling of the emission line ratios lead the authors to conclude that the two NV ratios imply supersolar metallicities in the broad line region of many high redshift quasars. They interpret the correlation in the NV diagram as a sequence in metallicity such that the highest redshift/most luminous objects show the highest metallicities ($\geq 10 \times Z\odot$).

When we plot the HzRG of our sample in the NV diagram, we were surprised to find that the radiogalaxies define a correlation parallel to the quasar line (see Fig.1, top left diagram). Our first idea was that we are witnessing, as for distant quasars, different levels of metal enrichment of the gas from object to object and, maybe, supersolar metallicities. An important difference with quasars is that we are talking about the *narrow line gas* (extended over several tens of kpc) rather than the broad lines gas (very close to the nucleus) studied by HF.

4. The models: Results

In order to test the validity of this interpretation it was first necessary to explore whether models other than a metallicity sequence could reproduce the observations: Villar-Martín et al. (1999) studied the effects of shock ionization (vs. active nucleus (AGN) photoionization), and the influence of the AGN continuum shape, density and/or ionization parameter (U)[1]. We showed that these models could not explain neither the NV correlation, neither the very strong NV emission observed in some objects.

[1] U is the quotient of the density of ionizing photons incident on the gas and the gas density: $U = \int_{\nu_0}^{oo} \frac{f_\nu d\nu/h\nu}{cn_H}$

We then investigated whether a metallicity sequence can explain the NV behaviour *and be consistent with the other emission line ratios.* Thanks to the high S/N of the spectra, we could use many emission lines (never detected before in HzRG) to test our models. We assumed that the gas (100 cm^{-3}) is photoionized by a power law of index α=-1.0 (Villar-Martín et al., 1999) and the same U=0.035 for all the objects (suggested by the little variation of CIV/CIII] and CIV/HeII, Fig.1).

We found that (see Fig.1, top left diagram):

* A sequence in metallicity can reproduce both the observed correlation and the strength of the NV emission. The heavy element abundances relative to H vary between 0.4 and 4 $\times Z\odot$

* The N abundance increases quadratically instead of linearly

* There is good agreement between the model predictions and the data *in most diagrams.* NIV]λ1488 is a problem. It is predicted to be stronger than observed. Non of the models we explored can explain this discrepancy. A similar inconsistency has been reported for the Seyfert galaxy NGC1068 (Kraemer & Crenshaw, 2000). However, the fact that both the data and the models define a tight correlation in the NIV diagram (see also OIII] diagram) supports a metallicity sequence.

5. Discussion and conclusions

Therefore, the NV diagram suggests:

* solar or supersolar metallicities in the extended gas of many HzRG

* different levels of enrichment from object to object

* quadratic increase of N abundance, suggesting dominant secondary N production. This is consistent with studies showing that secondary N production dominates at high metallicities (Henri et al., 2000).

HF concluded from the NV diagram that high redshift QSOs are associated with vigorous star formation that enriches the gas in short time scales ($\leq$1 Gyr, at least for z >4 objects). Chemical evolution models require a much faster evolution rate and a flatter IMF compared to the solar neighbourhood case. The high abundances we derive require similar models. This is the case of Giant Elliptical models (see §6.2 in HF99) and this supports the idea that HzRG (and quasars) are progenitors of giant ellipticals. Therefore, we conclude that also HzRG are undergoing intense star formation activity and we are witnessing the results of different evolutionary status in different objects. The unification model for powerful radio galaxies and quasars (Barthel, 1989) supports our interpretation. A more detailed discussion on the models and implications will be presented in Vernet et al. (2001).

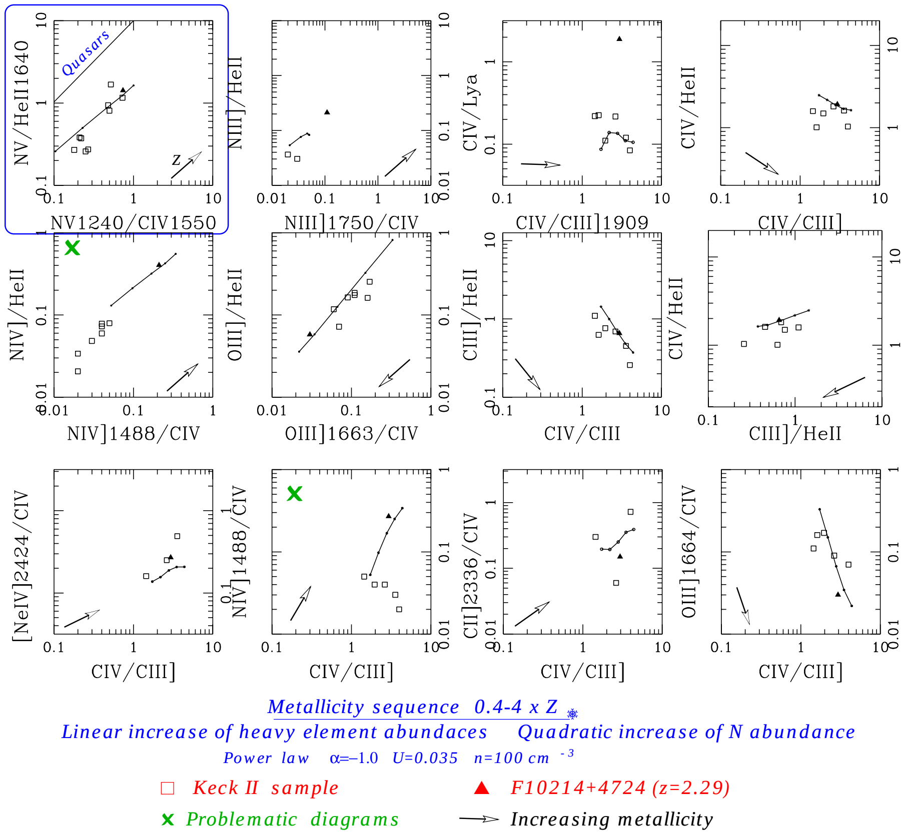

Figure 1. Diagnostic diagrams involving the strongest UV rest frame emission lines. The "NV diagram" is on the top left corner. The quasar correlation is also shown. HzRG define a parallel correlation. The solid line is our metallicity sequence for the HzRG sample. It shows good agreement with the data in most diagnostic diagrams..

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